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(54) **MATERIAL REMOVAL SYSTEM FOR USE WITH ARTICLES HAVING VARIATIONS IN FORM**

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B24B 27/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B24B 27/0038*** (2013.01); ***B24B 27/04*** (2013.01); *Y10T 29/49764* (2015.01); *Y10T 29/53022* (2015.01)

(58) **Field of Classification Search**
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USPC .... 29/26 R, 26 A, 26 B, 56.5; 73/627, 629; 76/108.1; 703/7
See application file for complete search history.

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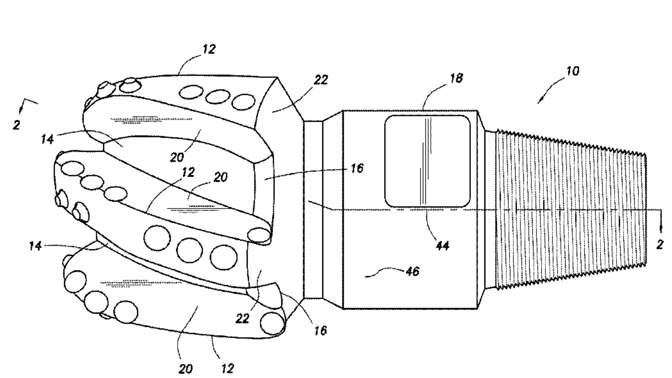
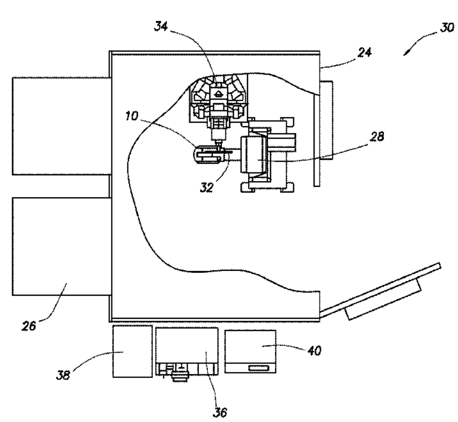
(57) **ABSTRACT**

A method of removing unwanted material from an article having a variable form can include scanning the article and determining, based on the scanning, a location of the unwanted material, determining tool paths of a cutting tool which will result in removal of the unwanted material, and displacing the cutting tool along the tool paths, thereby removing the unwanted material. A material removal system for removing unwanted material from an oilfield drill bit can include a rotary indexing device which rotates the drill bit about a longitudinal axis of the drill bit, a scanning device which scans an outer surface of the drill bit, and a controller which determines a geometry of the drill bit, based on at least one scan by the scanning device, determines a location of the unwanted material, and determines tool paths of a cutting tool for removal of the unwanted material.

34 Claims, 9 Drawing Sheets





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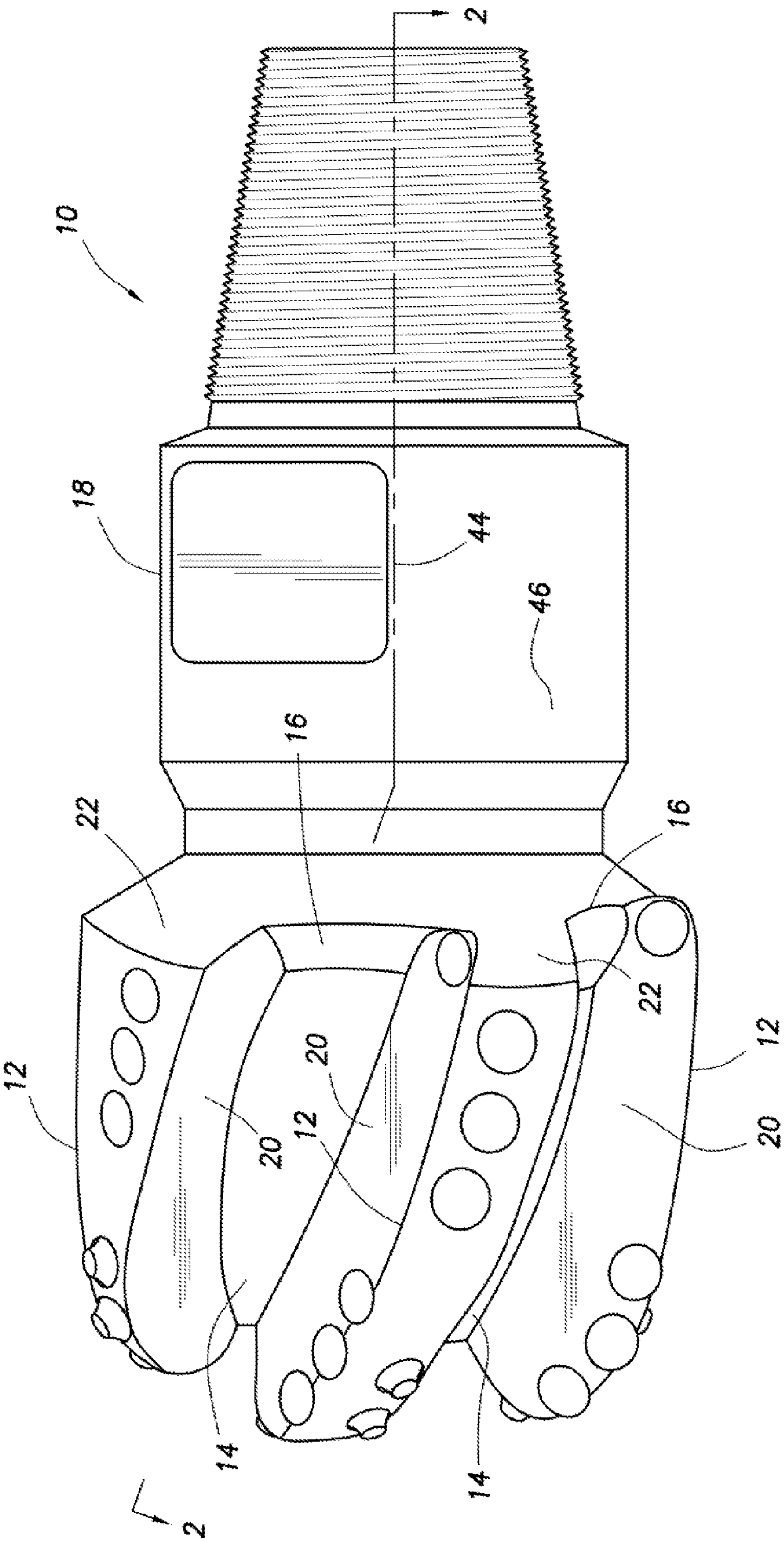


FIG. 1

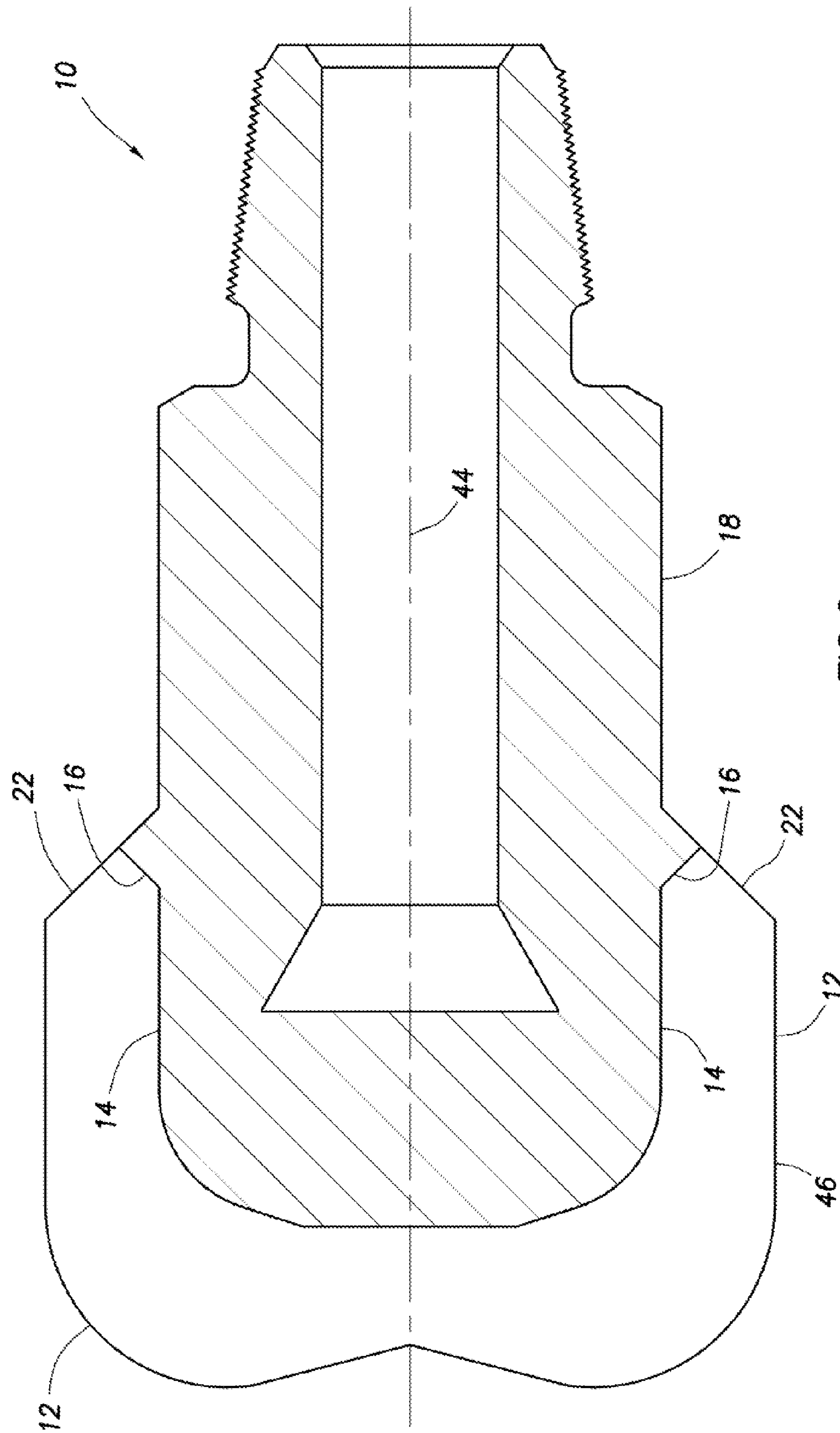


FIG.2

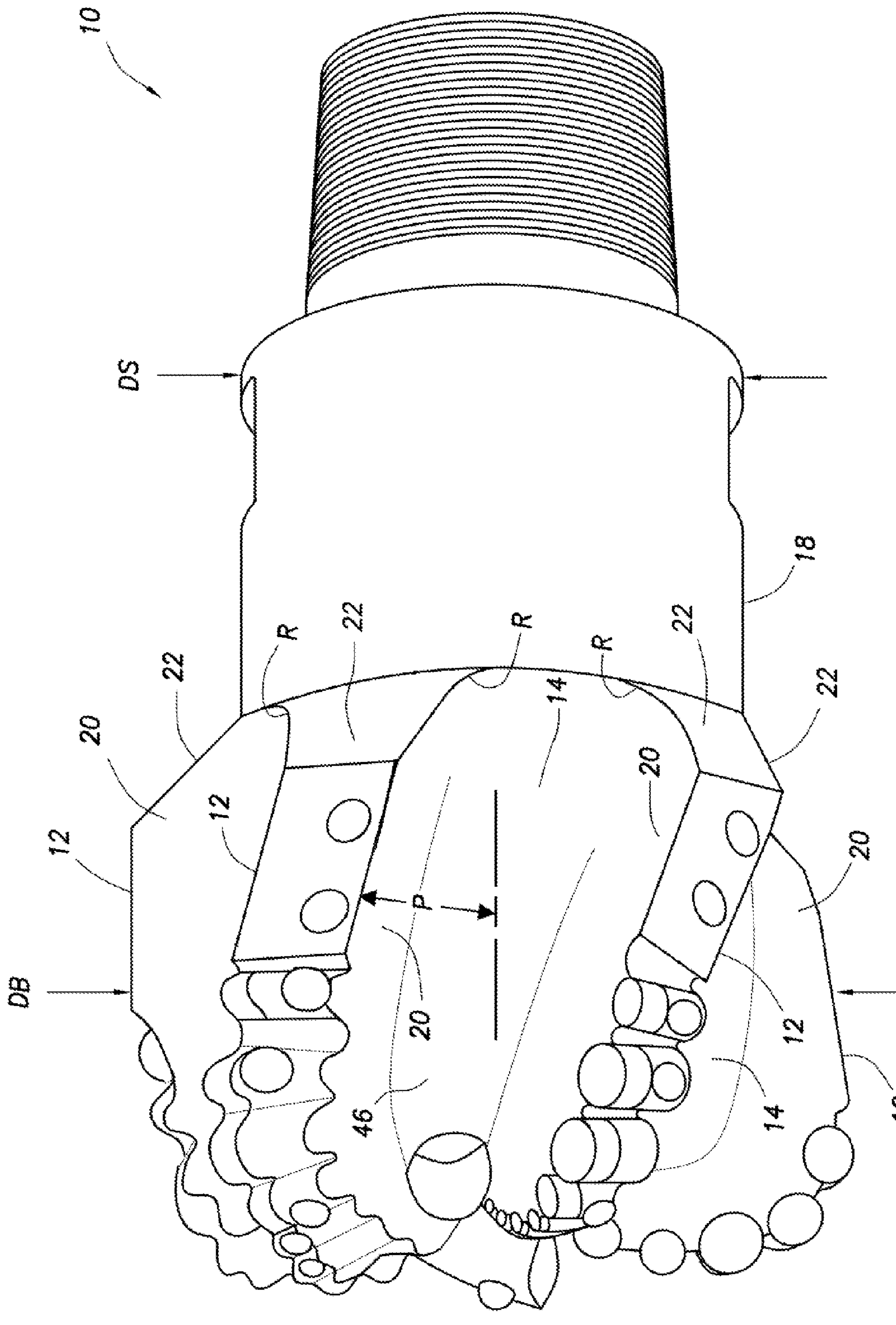


FIG.3

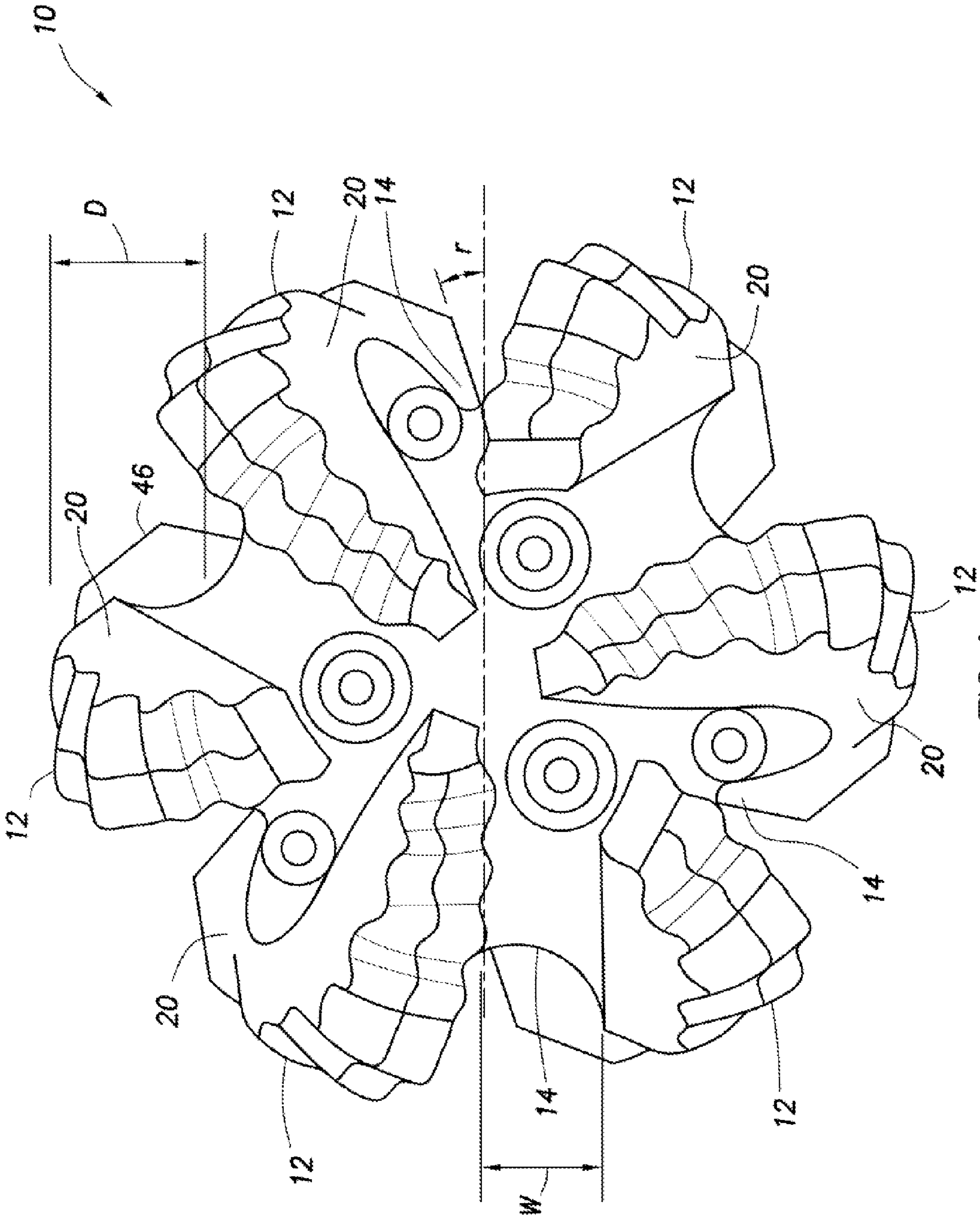


FIG.4

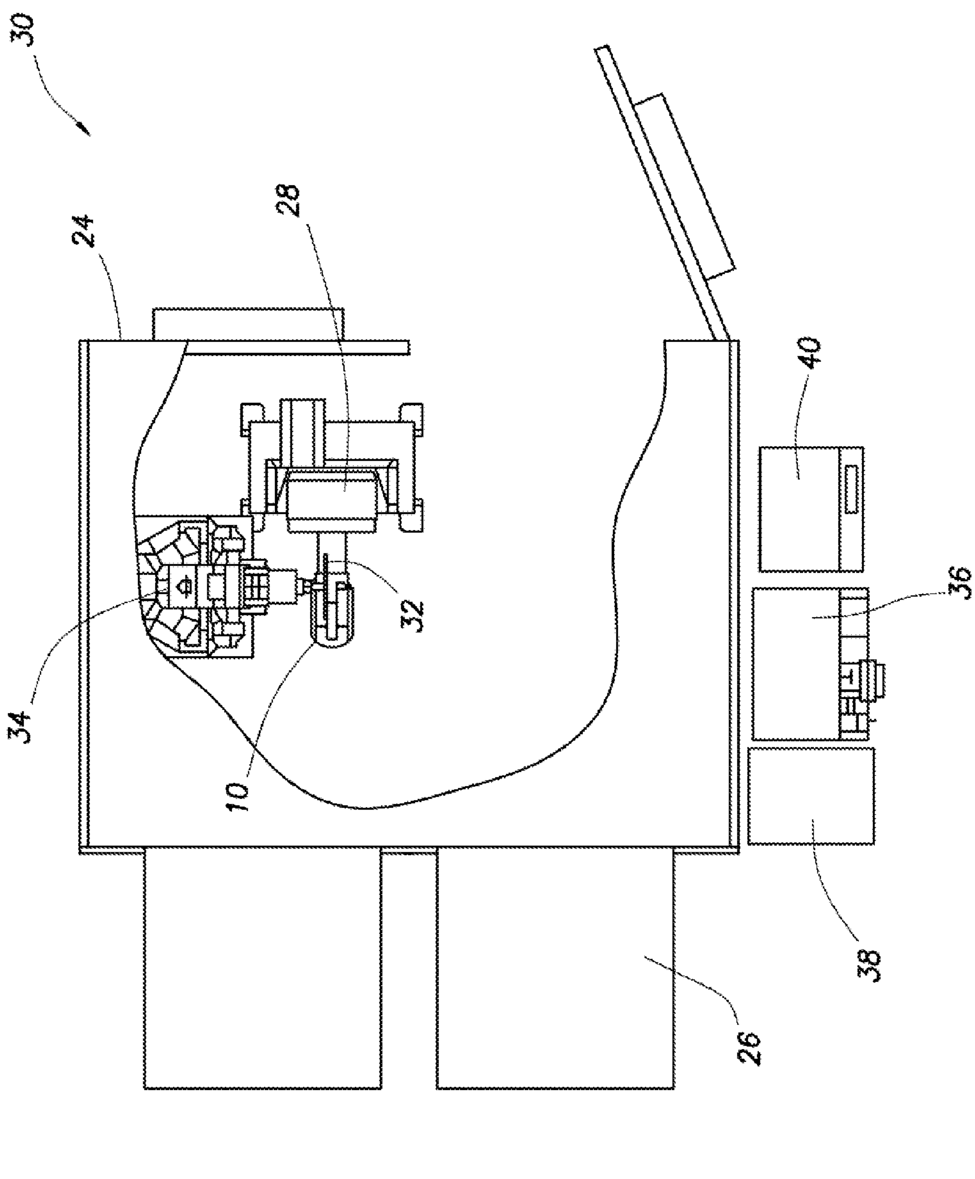


FIG.5

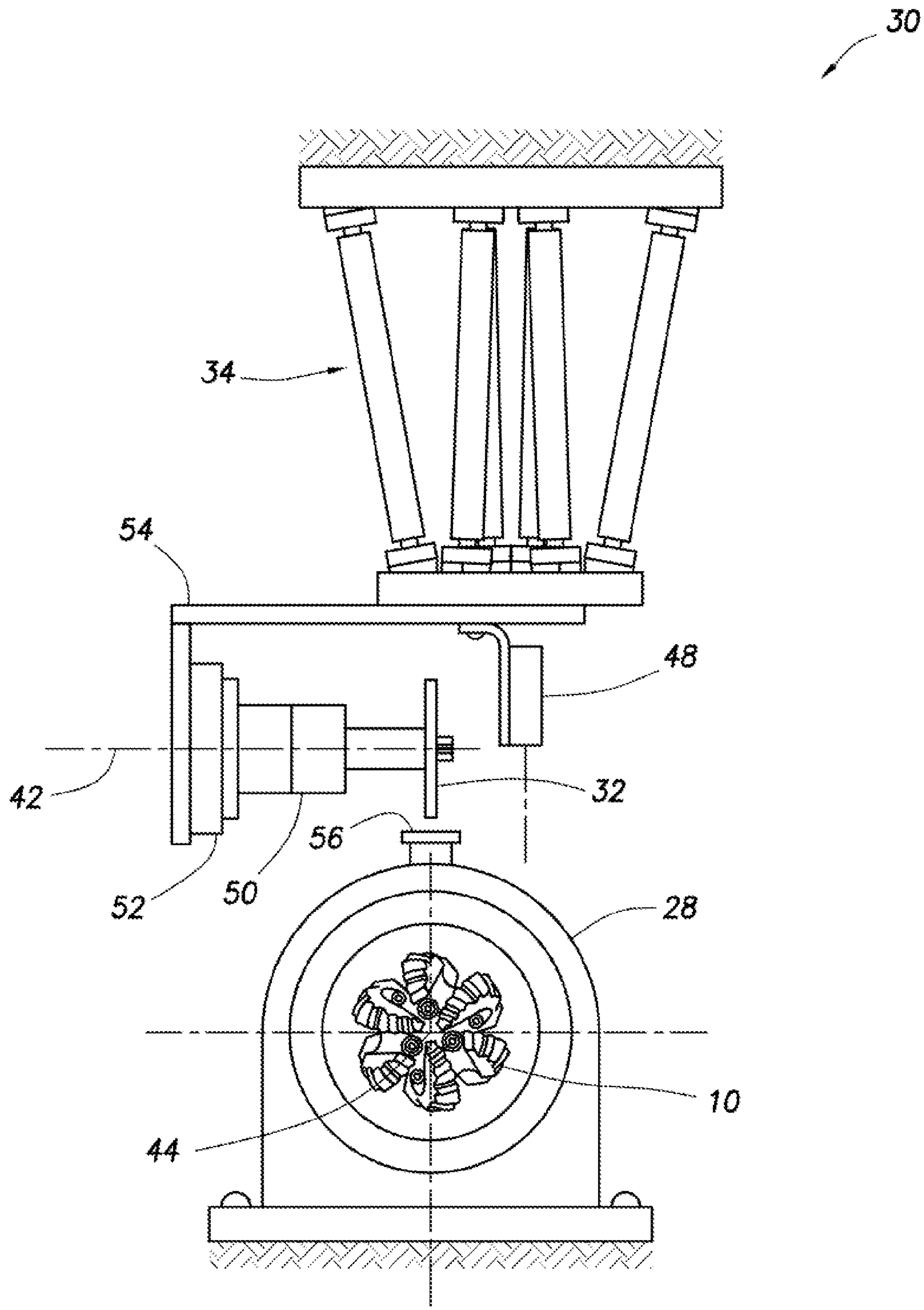


FIG.6

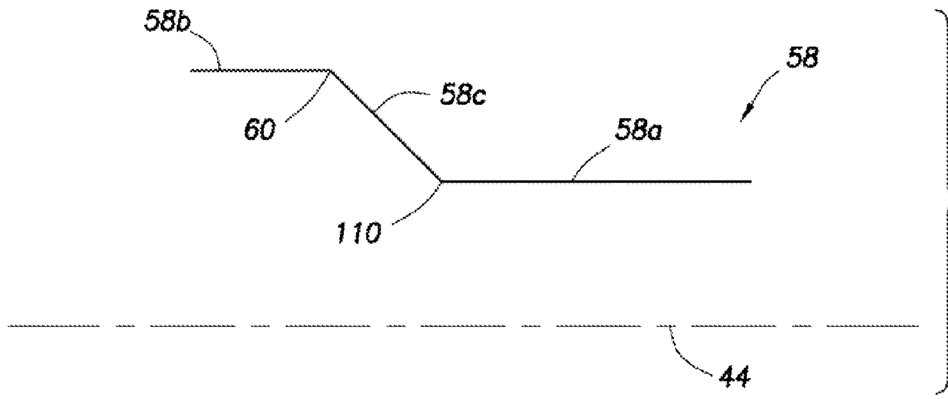


FIG.7

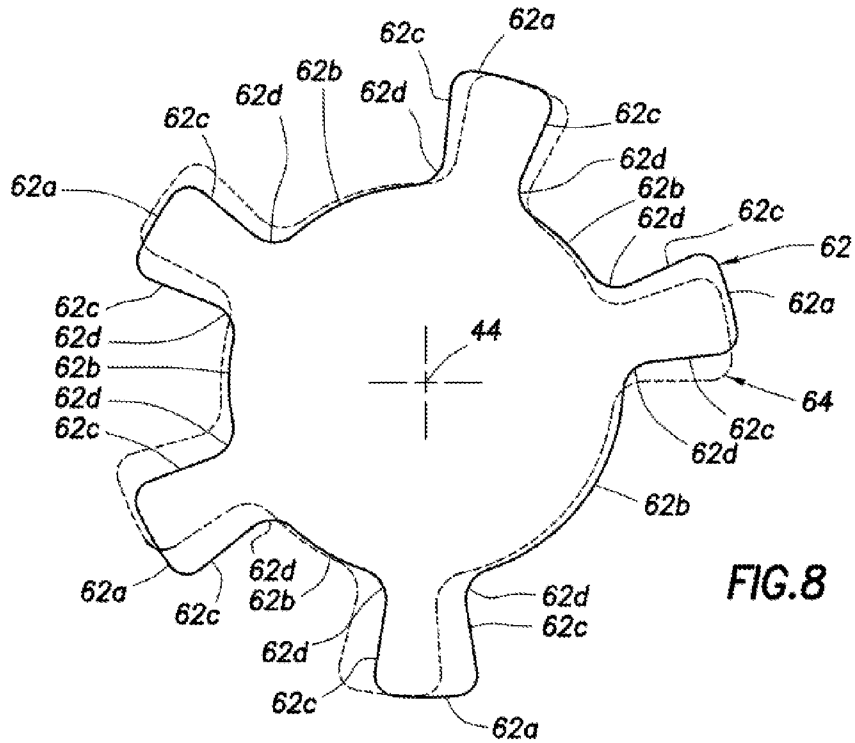


FIG.8

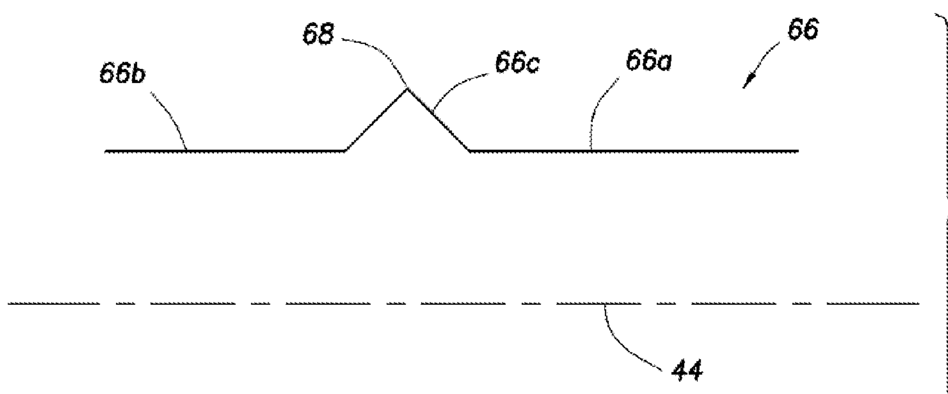
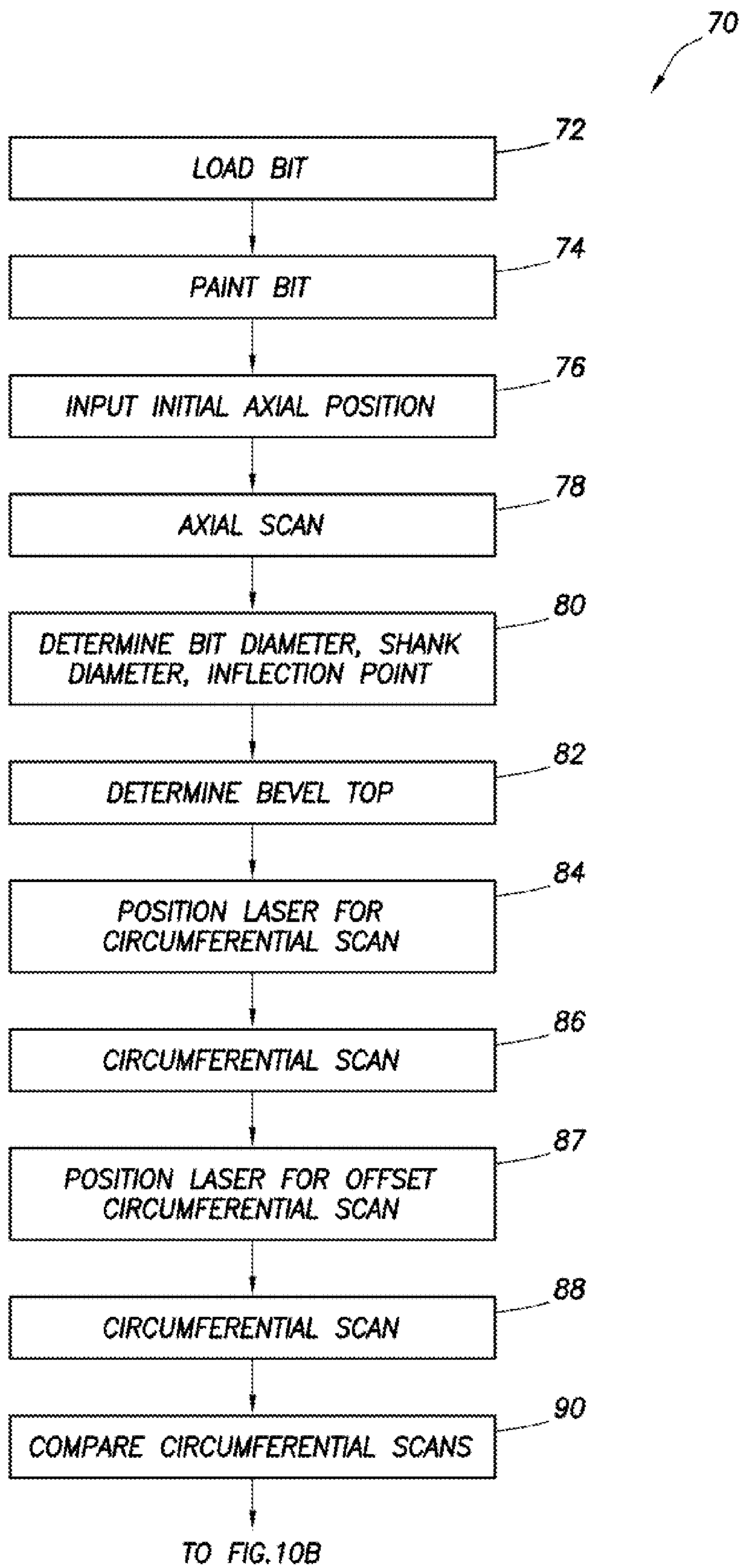


FIG.9

FIG. 10A


70
72
LOAD BIT
74
PAINT BIT
76
INPUT INITIAL AXIAL POSITION
78
AXIAL SCAN
80
DETERMINE BIT DIAMETER, SHANK DIAMETER, INFLECTION POINT
82
DETERMINE BEVEL TOP
84
POSITION LASER FOR CIRCUMFERENTIAL SCAN
86
CIRCUMFERENTIAL SCAN
87
POSITION LASER FOR OFFSET CIRCUMFERENTIAL SCAN
88
CIRCUMFERENTIAL SCAN
90
COMPARE CIRCUMFERENTIAL SCANS
TO FIG. 10B

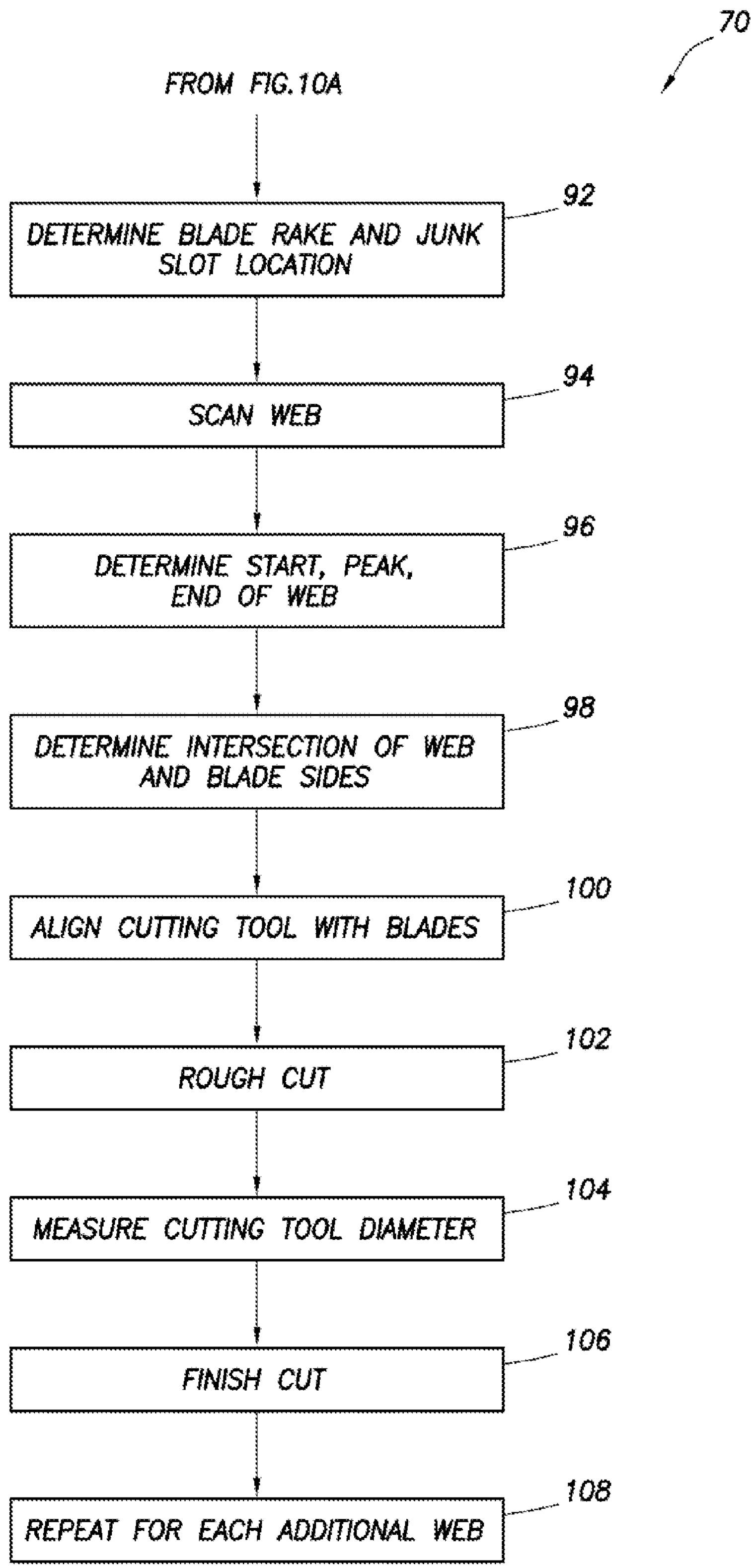

70
FROM FIG.10A
DETERMINE BLADE RAKE AND JUNK SLOT LOCATION
92
SCAN WEB
94
DETERMINE START, PEAK, END OF WEB
96
DETERMINE INTERSECTION OF WEB AND BLADE SIDES
98
ALIGN CUTTING TOOL WITH BLADES
100
ROUGH CUT
102
MEASURE CUTTING TOOL DIAMETER
104
FINISH CUT
106
REPEAT FOR EACH ADDITIONAL WEB
108

FIG.10B

MATERIAL REMOVAL SYSTEM FOR USE WITH ARTICLES HAVING VARIATIONS IN FORM

BACKGROUND

This disclosure relates generally to material removal systems and, in one example described below, more particularly provides an automated material removal system for use with custom manufactured oilfield drill bits.

Extensive personal protection equipment can be required for an operator to remove unwanted material from custom molded, cast or forged articles. However, the fact that the articles are custom manufactured prevents the use of typical automated material removal systems for removal of the unwanted material. For example, precise tool paths cannot be programmed into such a system, accounting for all possible variations in the articles.

Therefore, it will be appreciated that improvements are needed in the art of constructing material removal systems. Such improvements could be used for removing unwanted material from custom manufactured articles, or from other types of articles.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a representative side view of an oilfield drill bit.

FIG. **2** is a representative cross-sectional view of the drill bit, taken along line **2-2** of FIG. **1**.

FIG. **3** is a representative side view of another example of the oilfield drill bit.

FIG. **4** is a representative end view of the FIG. **3** example.

FIG. **5** is a representative top view of a material removal system which can embody principles of this disclosure.

FIG. **6** is a representative elevational view of certain components of the material removal system.

FIG. **7** is a representative axial scan of the drill bit.

FIG. **8** is are representative circumferential scans of the drill bit.

FIG. **9** is a representative helical scan of an unwanted web of the drill bit.

FIGS. **10** A & B comprise a representative flowchart for a method which can embody principles of this disclosure.

DETAILED DESCRIPTION

Representatively illustrated in FIGS. **1** & **2** is a drill bit **10** of the type used to drill wellbores through subterranean formations. The drill bit **10** is an example of an article which can benefit from having unwanted material thereon removed using a material removal system and method described below.

However, it should be clearly understood that the drill bit **10** is merely one of a wide variety of different types of articles which can benefit from the principles of this disclosure. Such articles are not necessarily limited to the oilfield. In particular (but not exclusively), articles which are cast, molded or forged, with significant variations in the articles, can most benefit from the principles described here, but the scope of this disclosure is not limited to cast, molded or forged articles.

Oilfield articles which can benefit from this disclosure's principles can comprise fixed cutter bits (such as the drill bit **10** depicted in FIGS. **1** & **2**), roller cone bits, coring bits, side picket mandrels, welded-together components (e.g., to remove excess weld material), hard facing, etc. Therefore, it will be appreciated that the scope of this disclosure is not limited to any of the details of the drill bit **10**, or of the material removal system and method described below for use with the drill bit.

The drill bit **10** has multiple generally helically formed blades **12**, with recesses **14** (known as "junk slots") between the blades. Note that, in other examples, the blades **12** may not be helically formed.

In an as-molded configuration as depicted in FIGS. **1** & **2**, the drill bit **10** also has unwanted material **16** between the blades **12**, which unwanted material could interfere with flow of fluids and cuttings through the recesses **14**. Therefore, the unwanted material **16** should be removed.

One problem with removing the material **16** using typical conventional automated material removal systems is that, in this example, the drill bit **10** is custom manufactured, with a certain geometry designed to suit a particular use of the drill bit. Thus, it would be impractical and inefficient in a relatively high volume manufacturing operation to produce custom programming for an automated material removal system each time a custom drill bit is manufactured.

Another problem with removing the material **16** using typical conventional automated removal systems is that, even if many of the custom designed drill bits **10** are manufactured, the molding process induces variations in the form of the blades **12**, the location of the unwanted material, etc. Thus, even if an automated material removal system were programmed with the geometry of the drill bit **10**, that geometry can change from bit to bit in practice, and so the system would not be able to adequately remove the unwanted material, without removing any wanted material (e.g., the blade **12** material, material of a shank **18** of the bit, etc.).

Referring additionally now to FIGS. **3** & **4**, another example of the drill bit **10** is representatively illustrated, with the unwanted material **16** removed. In this example, it may be seen that the blades **12** of the drill bit **10** have a helical pitch P, a radius R between each recess and sides **20** of adjacent blades, a width W between the blades, a depth D of the recess between the blades, a diameter DB of the blades, a diameter DS of the shank **18** and a bevel **22** between the blades and the shank.

It will be appreciated that, in order to determine the location of the unwanted material **16**, the geometry of the drill bit **10** should be determined (including, for example, the number and locations of the blades **12** and recesses **14**, the pitch P, the radius R between each recess and the sides **20** of adjacent blades, the width W between the blades, the depth D of the recess between the blades, the diameter DB of the blades, the diameter DS of the shank **18**, the bevel **22** between the blades and the shank, the location of the unwanted material, etc.). By determining the geometry of the drill bit **10** prior to the cutting operation, appropriate tool paths for displacement of a cutting tool relative to the drill bit can be determined, even though there may be variations in form of the drill bit.

Referring additionally now to FIG. **5**, a plan view of a material removal system **30**, and an associated method, which can embody principles of this disclosure is representatively illustrated. The system **30** in this example is configured for removing the unwanted material **16** from between the blades **12** of the drill bit **10**. However, in other examples, the system **30** could be used to remove unwanted material from other types of articles.

As depicted in FIG. **5**, the system **30** includes an enclosure **24** having a dust collector **26** for removing grinding dust, etc. from within the enclosure. The drill bit **10** is mounted in an axial indexing device **28** in the enclosure **24**. A cutting tool **32** (in this example, a grinding wheel) is displaced by a robot **34** along tool paths determined by a controller **36**.

The controller **36** can comprise at least one processor, memory devices and suitable programming for performing various functions. A suitable controller for use in the system **30** is a Model R30iA Controller manufactured by Fanuc Robotics, although other types of controllers may be used, if desired.

The system **30** also includes an operator terminal or user interface **38** (such as, an industrial computer with a display and an input device). A spindle chiller **40** draws heat from a spindle carrying the cutting tool **32**.

Referring additionally now to FIG. **6**, an elevational view of certain components of the system **30** is representatively illustrated. In this view, it may be seen that an axis **42** about which the cutting tool **32** rotates is oriented perpendicular to a longitudinal axis **44** of the drill bit **10** when the drill bit is mounted in the rotary indexing device **28**.

The robot **34** is of the six-axis type having multiple linear actuators. A suitable robot for use in the system **30** is a Model F-200iB manufactured by Fanuc Robotics of Rochester Hills, Mich. USA. Other robots, and other types of robots, may be used in keeping with the scope of this disclosure. Operation of the robot **34** is controlled by the controller **36**.

The rotary indexing device **28** rotates the drill bit **10** as needed to allow a scanning device **48** to appropriately scan an outer surface **46** of the bit (see FIGS. **1-4**), and to allow the cutting tool **32** to remove the unwanted material **16** from the bit. A suitable rotary indexing device for use in the system **30** is a Single Axis Positioner manufactured by Fanuc Robotics, although other rotary indexing devices may be used, if desired.

The scanning device **48** is used to determine the geometry of the drill bit **10** by scanning the outer surface **46** of the bit using certain techniques described more fully below. A suitable scanning device for use in the system **30** is a laser sensor with a dust tight, positively-pressured laser enclosure, a pneumatic shutter and hard guarding of the laser from collisions. Other types of scanning devices which may be used include radar, an ultrasound sensor, a physical probe and an optical scanning device (e.g., other than a laser), etc.

The cutting tool **32** is mounted to a spindle extending from a servo motor **50**. The servo motor **50** is mounted to an adjustable force device or active compliant tool **52**. A suitable active compliant tool for use in the system **30** is the 1000 Series Adjustable Force Device manufactured by PushCorp, Inc. of Dallas, Tex. USA, although use of the tool **52** is not necessary in the system, and other types of active compliant tools may be used in keeping with the scope of this disclosure.

A carriage **54** is used to mount the cutting tool **32**, device **48**, motor **50** and tool **52** to the robot **34**. In this manner, the cutting tool **32** and scanning device **48** can be displaced with six degrees of freedom (rotated and displaced along each of three axes) relative to the drill bit **10**.

In addition, the drill bit **10** can be rotated as desired relative to the robot **34**, cutting tool **32** and scanning device **48**. Since the robot **34** can manipulate the cutting tool **32** and scanning device **48** with six degrees of freedom, it is not necessary to rotate the drill bit **10** for the cutting tool and scanning device to adequately access the outer surface **46** of the drill bit. However, it is advantageous in the FIGS. **5** & **6** example to rotate the drill bit **10** for most convenient access to the outer surface **46** by the cutting tool **32** and scanning device **48**.

A horizontal plate **56** is provided at a known location for measuring a diameter of the cutting tool **32**. The robot **34** can position the cutting tool **32** above the plate **56**, and then slowly lower the cutting tool until it contacts the plate. The device **52** senses this contact (resulting in a force applied to the cutting tool **32**), and the controller **36** determines the diameter of the cutting tool, based on the position of the robot **34** when the contact occurs. Alternatively, the device **52** can sense deflection due to the contact in addition to, or instead of, sensing the actual contact to determine the diameter of the cutting tool **32**.

The cutting tool **32** in this example is a grinding wheel. The grinding wheel abrasively removes the unwanted material **16** from between the blades **12**. However, in other examples, the cutting tool **32** could comprise a circular mill or another type of cutting device.

Referring additionally now to FIG. **7**, a representative scan **58** produced by the scanning device **48** is illustrated. The scan **58** is produced by the robot **34** displacing the scanning device **48** axially along the outer surface **46** of the drill bit **10**, so that a blade **12** is axially traversed at least partially by the scan.

The axial scan **58** as depicted in FIG. **7** includes a section **58*a*** which indicates the diameter DS of the shank **18**, a section **58*b*** which indicates the diameter DB of a blade **12**, and a section **58*c*** which indicates the bevel **22**. The controller **36** can use the data from the axial scan **58** to determine the bit and shank diameters DB, DS, and the location and angle of the bevel **22**. Of interest in this example is locating a top **60** of the bevel **22** since, in a method described below, the top of the bevel can be used to determine the location of the blades **12** and the unwanted material **16**.

Referring additionally now to FIG. **8**, a representative circumferential scan **62** is illustrated. The scan **62** is produced in this example by the rotary indexing device **28** rotating the drill bit **10**, so that the blades **12** are traversed by the scan.

Many geometry characteristics of the drill bit **10** can be determined by the controller **36** from the data in the scan **62**. The number of the blades **12** and recesses **14** is readily determined, based on the circumferential scan **62**. The blade diameters DB and angular positions of the blades **12** are indicated by sections **62*a*** of the scan **62**, the positions of the recesses **14** are indicated by sections **62*b***, the rakes of the blade sides **20** are indicated by sections **62*c***, the widths W between adjacent blades **12** are indicated by the distances between the sections **62*c***, the depths D of the recesses **14** are indicated by differences between the sections **62*a*** & ***b***, radii R between the recesses **14** and adjacent sides of the blades are indicated by sections **62*d***. In effect, the circumferential scan **62** gives a lateral cross-sectional representation of the drill bit **10** at a certain axial position along the bit.

To determine how the geometry of the blades **12** changes along their length, another circumferential scan **64** is performed at another axial position. By determining the change in angular positions of the blades **12** between the two circumferential scans **62** & **64**, the helical pitch P of the blades can be readily calculated. The helical pitch P may be expressed in angular units (e.g., relative to the longitudinal axis **44**, as in FIG. **3**), or in any other units.

The controller **36** can identify the various sections of the circumferential scans **62**, **64**, and compare the scans to determine the geometrical characteristics of the drill bit **10**. Data manipulation techniques may be used, e.g., data validation, averaging measurements, etc., to produce accurate geometrical information on the drill bit **10**, from which appropriate tool paths for the cutting tool **32** can be determined.

Referring additionally now to FIG. **9**, another scan **66** is performed by the scanning device **48**. The scan **66** in this example helically traverses the drill bit **10** outer surface **46** between the shank **18** and a recess **14**. In this manner, the scan **66** also traverses the unwanted material **16** between the blades **12**.

This scan **66** is performed after the circumferential scans **62**, **64** so that the helical pitch P and the angular positions of the blades **12** are known prior to the scan **66**. With the positions and pitches P of the blades **12** known, the controller **36** can direct the robot **34** to displace the scanning device **48** axially while the rotary indexing device **28** rotates the drill bit **10**, thereby helically scanning between the shank **18** and a recess **14**.

The scan **66** includes a section **66***a* (similar to the section **58***a* in FIG. **7**) which indicates the shank diameter DS, a section **66***b* (similar to the sections **62***b*) which indicates the depth of the recess **14**, and a section **66***c* which indicates the unwanted material **16** between the blades **12**. Preferably, a peak of the section **66***c* can be identified as a peak **68** of the corresponding unwanted material **16**.

The controller **36** can determine from the scans **58**, **62**, **64**, **66** the various geometrical characteristics of the drill bit **10**, including the location of the unwanted material **16** between the blades **12**. To remove this unwanted material **16**, the controller **36** can determine appropriate tool paths of the cutting tool **32** which will result in removal of the unwanted material, without removing any of the wanted material of the drill bit **10**.

Referring additionally now to FIGS. **10**A & B, a method **70** of removing the unwanted material **16** from the drill bit **10** is representatively illustrated in flowchart form. Although the method **70** is suited for removing the unwanted material **16** from the drill bit **10**, with appropriate modification, the method could be used for removing unwanted material from other types of articles.

In one aspect, the method **70** accomplishes a desirable result of removing the unwanted material **16**, even though the precise geometry of the drill bit **10** is unknown before commencement of the method. An operator can input (e.g., via the interface **38**) an approximate size of the drill bit **10**, as well as other identifying characteristics, so that the controller **36** has a basis for beginning the process of determining the drill bit's geometry.

In step **72**, the drill bit **10** is loaded into the rotary indexing device **28**, so that the longitudinal bit axis **44** is centered in the device's rotor.

In step **74**, the drill bit **10** is painted so that the scanning device **48** can readily detect the outer surface **46** of the bit. This step **74** is optional if the scanning device **48** can accurately detect the outer surface **46** without it being painted.

In step **76**, the operator inputs an initial axial position into the interface **38**. The controller **36** uses this information to determine where to start the axial scan **58**. In this example, the initial axial position is on the shank **18**, somewhat toward the indexing device **28** from the bevel **22**. The controller **36** ignores any data for axial positions opposite the blades **12** from the initial axial position.

In step **78**, the axial scan **58** is performed. The robot **34** displaces the scanning device **48** so that the scan **58** traverses the drill bit **10** from the shank **18** to a blade **12**.

In step **80**, the controller **36** determines the bit diameter DB, the shank diameter DS and an inflection point **110** of the bevel **22** (diameter reductions along the shank **18** can be ignored in determination of the inflection point **110** position). These determinations are, in this example, based on the information obtained from the axial scan **58**, as discussed above in relation to FIG. **7**. In addition, the operator can input to the interface **38** an angle of the bevel **22** (e.g., 30 or 45 degrees, etc.).

In step **82**, the controller **36** determines the location of the bevel top **60**. In this example, the location of the bevel top **60** can be readily calculated, since the location of the inflection point **110** and the angle of the bevel **22** are known.

In step **84**, the robot **34** positions the scanning device **48** (a laser in this example) for circumferentially scanning the outer surface **46** of the drill bit **10**. The drill bit **10** can be rotated by the rotary indexing device **28** relative to the scanning device **48**. In other examples, the scanning device **48** could be rotated about the drill bit **10** (e.g., by the robot **34**).

In step **86**, the drill bit **10** is circumferentially scanned by the scanning device **48** at a first axial position along the drill bit. In this example, the axial position is chosen to be in the area of the blades **12**, so that the circumferential scan **62** will allow for geometrically characterizing each of the blades and recesses **14** about the drill bit **10**, as discussed above in relation to FIG. **8**.

For example, the number of the blades **12** and recesses **14**, the blade diameters DB and angular positions of the blades (e.g., as indicated by sections **62***a* of the scan **62**), the positions of the recesses (e.g., as indicated by sections **62***b*), the rakes r (e.g., see FIG. **4**) of the blade sides **20** (e.g., as indicated by sections **62***c*), the widths W between adjacent blades **12** (e.g., as indicated by the distances between the sections **62***c*), the depths D of the recesses **14** (e.g., as indicated by differences between the sections **62***a* & *b*) and radii R (e.g., as indicated by sections **62***d*) can be readily determined from such a circumferential scan **62**.

In step **87**, the scanning device **48** is repositioned to a second axial position, offset from the first axial position in step **86**.

In step **88**, the drill bit **10** is circumferentially scanned by the scanning device **48** at the second axial position along the drill bit. The second axial position is also in the area of the blades **12** in this example, but is axially offset from the first circumferential scan in step **86**, so that certain changes in geometrical characteristics can be determined.

In step **90**, the circumferential scans **62** & **64** are compared. For example, by calculating the change in angular positions of the blades **12** between the two circumferential scans **62** & **64**, the helical pitch P of the blades can be readily determined by the controller **36**, as discussed above in relation to FIG. **8**.

In step **92**, the blade rake r is determined by the controller **36**, based on the circumferential scan **62**. For example, the controller **36** can pick two points on a side **20** of a blade **12** (e.g., as indicated by the corresponding scan section **62***c*), and compare their positions in order to calculate the blade rake r. The locations of the recesses **14** (also known to those skilled in the art as "junk slots") can be readily determined, as well (e.g., at sections **62***b* of the circumferential scan **62**).

In step **94**, the robot **34** positions the scanning device **48**, and the rotary indexing device **28** rotates the drill bit, so that the scanning device can scan the outer surface **46** of the drill bit helically along one of the recesses **14**. The rotary indexing device **28** then rotates the drill bit **10** while the robot **34** displaces the scanning device **48** axially relative to the drill bit, thereby helically scanning the outer surface of the drill bit. However, the robot **34** could displace the scanning device **48** helically about the drill bit **10** (e.g., so that the drill bit is not rotated during the helical scan), if desired.

In this example, the unwanted material **16** comprises a web between the blades **12**, resulting from a molding process. However, in other examples, the unwanted material **16** may be be removed from another type of drill bit, or another type of oilfield equipment, or other type of article. Furthermore, the unwanted material **16** may not comprise a web, the article or drill bit may not be produced by a molding process, etc. Thus, it should be clearly understood that the principles of this disclosure are not limited to the details of the method **70** or the drill bit **10** described herein or depicted in the drawings.

In step **96**, the controller **36** determines the start, peak and end of the unwanted material **16** (a web in this example). As described above, a peak of the section **66***c* (see FIG. **9**) can be identified as a peak **68** of the corresponding unwanted material **16**.

In step **98**, the controller **36** determines where the web intersects the wanted material of the blade **12** sides **20**, recesses **14** and radii R. Tool paths for the cutting tool **32** are then calculated, so that the unwanted material **16** will be removed, up to the intersections between the unwanted material and the blade sides **20**, recesses **14** and radii R.

In step **100**, the controller **36** rotates the drill bit (if needed) and aligns the cutting tool **32** with a recess **14** between two blades **12**. For example, the robot **34** could rotate the cutting tool **32** so that it is at a same angle (considering the cutting tool as being normal to the axis **42**) relative to the longitudinal axis **44** of the drill bit **10** as the helical pitch P of the blades **12** adjacent the selected recess **14**.

The robot **34** can also rotate the cutting tool **32** so that it is angled to correspond with the rake r of the adjacent blade sides **20**. In this manner, the cutting tool **32** can be conveniently displaced between the blades **12** for removal of the unwanted material **16**, without removing any of the wanted material of the blade sides **22**, radii R or recesses **14**.

In step **102**, the cutting tool **32** rough cuts the unwanted material **16**. In this example, the cutting tool **32** is plunged radially (relative to the bit axis **44**) into the unwanted material **16** between the blades **12**, and then is displaced axially to remove the axial width of the unwanted material. This process is repeated, with the drill bit **10** being rotated by the rotary indexing device **28** as needed between sets of radial plunges and axial displacements, to remove the unwanted material **16** up to near the intersection between the unwanted material and the blade sides **20**, radii R and recess **14**.

In step **104**, the cutting tool **32** diameter is again measured, since abrasive rough cutting can reduce the cutting tool diameter. In this example, the cutting tool **32** is displaced by the robot **34** into contact with the plate **56**, the device **52** senses such contact and/or displacement, and the controller **36** uses this information to compute the diameter of the cutting tool. If an abrasive cutting tool is not used, then step **104** may not be performed in the method **70**.

In step **106**, the cutting tool **32** finish cuts the unwanted material **16**. In this example, the cutting tool **32** initially plunge cuts partially into the unwanted material **16** near one of the radii R and at the axial start of the unwanted material, the drill bit **10** rotates to displace the center of the recess **14** toward the cutting tool. This is repeated at both sides **20** adjacent the recess **14**, and at the axial middle and end of the unwanted material **16**. Multiple passes at incrementally decreasing radial distances from the bit axis **44** can be performed, until the cutting tool **32** has removed substantially all of the unwanted material **16**.

In step **108**, the preceding steps **94-106** are repeated for each successive portion of unwanted material **16** between adjacent blades **12**. Certain determinations made in, for example, steps **80**, **82**, **90**, **92** can also be used by the controller **36** in determining tool paths for the cutting tool **32** in the repeated steps **94-106**. Although in this example, certain scans **58**, **62**, **64** may not be repeated in the repeated steps **94-106**, in other examples any or all of these scans could be repeated, as desired.

Note that it is not necessary for substantially all of the unwanted material **16** to be removed from between the blades **12**. For example, in order to protect wanted material of the drill bit **10**, the controller **36** could prevent the cutting tool **32** from removing unwanted material adjacent to the wanted material. Such a situation could arise, for example, if the bit is undercut, a weld groove is present, etc.

Furthermore, note that it is not necessary for all of the steps **72-108** described above to be performed in keeping with the scope of this disclosure. In other examples, more, fewer or different steps could be performed, and the steps could be performed in different orders. For example, step **92** could be part of step **86**, the second circumferential scan **64** may not be performed if the blade pitch P is known, etc. Thus, it will be appreciated that the scope of this disclosure is not limited at all to the details of the method **70** described here or depicted in the drawings.

If the blades **12** do not have a helical pitch P, then the helical scan **66** can instead be an axial scan, since the recesses **14** would not extend helically about the drill bit **10**. In addition, if there is no helical pitch P, the cutting tool **32** may not be rotated to align with the nonexistent helical pitch. Similar considerations apply if the blades **12** have no rake r (e.g., the cutting tool **32** would not be rotated to align with the nonexistent rake).

It may now be fully appreciated that the material removal system **30** and method **70** result from significant advancements in the art of material removal. Especially (although not exclusively) useful for custom manufactured articles having variations in form, the system **30** and method **70** allow the unwanted material **16** to be efficiently and safely removed, without removing any of the wanted material of the drill bit **10**.

In one example, a method **70** of removing unwanted material **16** from an oilfield drill bit **10** is provided to the art by the above disclosure. The method **70** can include scanning the drill bit **10**; determining, based on the scanning, a location of the unwanted material **16**; determining tool paths of a cutting tool **32** which will result in removal of the unwanted material **16**; and displacing the cutting tool **32** along the tool paths, thereby removing the unwanted material **16**.

The unwanted material **16** may be positioned between blades **12** of the drill bit **10**.

Determining the location of the unwanted material **16** can include determining radii R between a recess **14** and adjacent sides **20** of the blades **12**.

Scanning can comprise scanning helically along a surface **46** of the drill bit **10** between the blades **12**.

Determining the location of the unwanted material **16** can include determining a width W between the blades **12**, determining a number of the blades **12**, determining an angular spacing of the blades **12**, determining a helical pitch P of the blades **12**, determining a rake r of the blades **12**, and/or determining a depth D between the blades **12**.

Displacing the cutting tool **32** can include displacing the cutting tool **32** to approximately the depth D between the blades **12**, thereby removing the unwanted material **16** positioned outward from the depth D.

Displacing the cutting tool **32** can include displacing the cutting tool **32** along the tool paths aligned with the helical pitch P.

Determining the helical pitch P can include circumferentially scanning the blades **12** at axially spaced apart positions.

Scanning can comprise scanning axially along a surface **46** of the drill bit **10**. Determining the location of the unwanted material **16** can comprise determining at least one of the group comprising a drill bit diameter DB, a shank diameter DS, an inflection point **110** and a bevel top **60**, based on the axial scanning.

Scanning can comprise scanning circumferentially about blades **12** of the drill bit **10**. Determining the location of the unwanted material **16** can include determining at least one of the group comprising number of the blades **12**, angular spacing of the blades **12**, widths W between the blades **12**, radii R at sides **20** of the blades **20**, rake r of the blades **12** and helical pitch P of the blades **12**, based on the circumferential scanning.

A material removal system **30** is also provided to the art for removing unwanted material **16** from an oilfield drill bit **10**. In one example, the system **30** can include a rotary indexing device **28** which rotates the drill bit **10** about a longitudinal axis **44** of the drill bit **10**, a scanning device **48** which scans an outer surface **46** of the drill bit **10** and a controller **36** which a) determines a geometry of the drill bit **10**, based on at least one scan **58**, **62**, **64**, **66** by the scanning device **48**, b) determines a location of the unwanted material **16**, and c) determines tool paths of a cutting tool **32** for removal of the unwanted material **16**.

The scanning device **48** may comprises a laser, radar, an ultrasound sensor, a physical probe and/or an optical scanning device.

The location of the unwanted material **16** and/or the geometry of the drill bit **10** may be unknown until determined by the controller **36**.

There may be relative rotation between the drill bit **10** and the scanning device **48** while the scanning device **48** scans the outer surface **46** of the drill bit **10**. The rotary indexing device **28** may rotate the drill bit **10** while the cutting tool **32** removes the unwanted material **16**.

The drill bit **10** geometry determined by the controller **36** may comprise radii R between a recess **14** and adjacent sides **20** of the blades **12**, a width W between the blades **12**, a number of the blades **12**, an angular spacing of the blades **12**, a depth D between the blades **12**, a helical pitch P of the blades **12**, and/or a rake r of the blades **12**.

The controller **36** can displace the cutting tool **32** along the tool paths aligned with the helical pitch P.

The controller **36** can determine the helical pitch P based on multiple circumferential scans **62**, **64** of the blades **12** at axially spaced apart positions.

The scanning device **48** can scan axially along the outer surface **46** of the drill bit **10**, whereby an axial scan **58** is produced. The drill bit **10** geometry determined by the controller **36** can comprise a drill bit diameter DB, a shank diameter DS, an inflection point **110**, and/or a bevel top **60**, based on the axial scan **58**.

The scanning device **48** can scan circumferentially about blades **12** of the drill bit **10**, whereby one or more circumferential scans **62**, **64** are produced. The drill bit **10** geometry determined by the controller **36** can comprise a number of the blades **12**, an angular spacing of the blades **12**, widths W between the blades **12**, radii R at sides **20** of the blades **12**, rake r of the blades **12**, and/or helical pitch P of the blades **12**, based on the one or more circumferential scans **62**, **64**.

As mentioned above, the scope of this disclosure is not limited to use only in removing unwanted material from an oilfield drill bit. In a broader aspect, a method **70** of removing unwanted material **16** from an article (e.g., the drill bit **10** or another article) having a variable form is described by this disclosure. In one example, the method **70** can include scanning the article; determining, based on the scanning, a location of the unwanted material **16**; determining tool paths of a cutting tool **32** which will result in removal of the unwanted material **16**; and displacing the cutting tool **32** along the tool paths, thereby removing the unwanted material **16**.

Scanning can comprise scanning axially helically and/or circumferentially along a surface **46** of the article.

The article may be rotated during the scanning.

Scanning circumferentially may be performed at multiple axial positions along the article.

The article may be rotated while removing the unwanted material **16**. The article may be displaced while displacing the cutting tool **32**.

Removing the unwanted material **16** may comprise grinding away the unwanted material **16**.

The scanning may be performed by a laser, radar, an ultrasound sensor, a physical probe, and/or an optical scanning device.

The location of the unwanted material **16** may be unknown prior to the scanning. The form of the article may be unknown prior to the scanning.

Although various examples have been described above, with each example having certain features, it should be understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted in the drawings can be combined with any of the examples, in addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope of this disclosure encompasses any combination of any of the features.

Although each example described above includes a certain combination of features, it should be understood that it is not necessary for all features of an example to be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

It should be understood that the various embodiments described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific details of these embodiments.

In the above description of the representative examples, directional terms (such as "above," "below," "upper," "lower," etc.) are used for convenience in referring to the accompanying drawings. However, it should be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system, method, apparatus, device, etc., is described as "including" a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can also include other features or elements. Similarly, the term "comprises" is considered to mean "comprises, but is not limited to."

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the invention being limited solely by the appended claims and their equivalents.

What is claimed is:

1. A method of removing unwanted material from an oilfield drill bit, the method comprising:

scanning an outer surface of the oilfield drill bit with a device located external to the oilfield drill bit;

determining, based on the scanning, a location of the unwanted material positioned between a plurality of blades on the outer surface of the oilfield drill bit;

calculating, based on the scanning, a helical pitch of the of blades;

determining tool paths of a cutting tool which will result in removal of the unwanted material, the tool paths aligned with the helical pitch of the plurality of blades; and

displacing the cutting tool along the tool paths, to remove the unwanted material.

2. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining radii between a recess and adjacent sides of the plurality of blades.

3. The method of claim **1**, wherein scanning further comprises scanning helically along a surface of the oilfield drill bit between the plurality of blades.

4. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining a width between the plurality of blades.

5. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining a number of the plurality of blades.

6. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining an angular spacing of the plurality of blades.

7. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining a depth between the plurality of blades.

8. The method of claim **7**, wherein displacing the cutting tool comprises displacing the cutting tool to approximately the depth between the plurality of blades, thereby removing the unwanted material positioned outward from the depth.

9. The method of claim **1**, wherein displacing the cutting tool comprises displacing the cutting tool along the tool paths aligned with the helical pitch.

10. The method of claim **1**, wherein determining the helical pitch comprises circumferentially scanning the plurality of blades at axially spaced apart positions.

11. The method of claim **1**, wherein determining the location of the unwanted material further comprises determining a rake of the plurality of blades.

12. The method of claim **1**, wherein scanning comprises scanning axially along a surface of the oilfield drill bit.

13. The method of claim **12**, wherein determining the location of the unwanted material comprises determining at least one of the group comprising a drill bit diameter, a shank diameter, an inflection point and a bevel top, based on the axial scanning.

14. The method of claim **1**, wherein scanning comprises scanning circumferentially about the plurality of blades of the oilfield drill bit.

15. The method of claim **14**, wherein determining the location of the unwanted material comprises determining at least one of the group comprising number of the plurality of blades, angular spacing of the plurality of blades, widths between the plurality of blades, radii at sides of the plurality of blades, and rake of the plurality of blades, based on the circumferential scanning.

16. A material removal system for removing unwanted material from an oilfield drill bit, the system comprising:

a rotary indexing device which rotates the oilfield drill bit about a longitudinal axis of the oilfield drill bit;

a scanning device which scans an outer surface of the oilfield drill bit, the scanning device located external to the oilfield drill bit; a cutting tool which removes the unwanted material from the oilfield drill bit; and

a controller which a) determines a geometry of the oilfield drill bit, based on at least one scan by the scanning device, b) determines a location of the unwanted material positioned between a plurality of blades on the outer surface of the oilfield drill bit, c) calculates a helical pitch of the of blades, d) determines tool paths of the tool for removal of the unwanted material, the tool paths aligned with the helical pitch of the plurality of blades, and e) displaces the cutting tool along the tool path to remove the unwanted material.

17. The system of claim **16**, wherein the scanning device comprises at least one of the group comprising a laser, radar, an ultrasound sensor, a physical probe and an optical scanning device.

18. The system of claim **16**, wherein the location of the unwanted material is unknown until determined by the controller.

19. The system of claim **16**, wherein the geometry of the oilfield drill bit is unknown until determined by the controller.

20. The system of claim **16**, wherein there is relative rotation between the oilfield drill bit and the scanning device while the scanning device scans the outer surface of the oilfield drill bit.

21. The system of claim **16**, wherein the rotary indexing device rotates the oilfield drill bit while the cutting tool removes the unwanted material.

22. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises radii between a recess and adjacent sides of the plurality of blades.

23. The system of claim **16**, wherein the scanning device scans helically along the outer surface of the oilfield drill bit between plurality of blades.

24. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises a width between the plurality of blades.

25. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises a number of the plurality of blades.

26. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises an angular spacing of plurality blades.

27. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises a depth between the plurality of blades.

28. The system of claim **16**, wherein the controller displaces the cutting tool along the tool paths aligned with the helical pitch.

29. The system of claim **16**, wherein the controller determines the helical pitch based on multiple circumferential scans of the plurality of blades at axially spaced apart positions.

30. The system of claim **16**, wherein the oilfield drill bit geometry determined by the controller comprises a rake of the plurality of blades.

31. The system of claim **16**, wherein the scanning device scans axially along the outer surface of the oilfield drill bit, whereby an axial scan is produced.

32. The system of claim **31**, wherein the oilfield drill bit geometry determined by the controller comprises at least one of the group comprising a drill bit diameter, a shank diameter, an inflection point and a bevel top, based on the axial scan.

33. The system of claim **16**, wherein the scanning device scans circumferentially about plurality of blades of the oilfield drill bit, whereby one or more circumferential scans are produced.

34. The system of claim **33**, wherein the oilfield drill bit geometry determined by the controller comprises at least one of the group comprising number of the plurality of blades, angular spacing of the plurality of blades, widths between the plurality of blades, radii at sides of the plurality of blades, rake of the plurality of blades and rake of the plurality of blades, based on the one or more circumferential scans.

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